EXHIBIT

A

Physics

PARTS I and II

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Physics for Students of Science and Engineering
Part I

Signed,
Sin θ and his friend arctan.
Love,
i.e. θ + tan⁻¹!

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A current loop sets up a magnetic field at distant points like that of a magnetic dipole, one face of the loop being a north pole, the opposite face being a south pole. The north pole, as for bar magnets, is that face *from* which the lines of **B** emerge. If, as Lenz's law predicts, the loop in Fig. 35-3 is to oppose the motion of the magnet toward it, the face of the loop toward the magnet must become a north pole. The two north poles—one of the current loop and one of the magnet—will repel each other. The right-hand rule shows that for the magnetic field set up by the loop to emerge from the right face of the loop the induced current must be as shown. The current will be counterclockwise as we sight along the magnet toward the loop.

When we push the magnet toward the loop (or the loop toward the magnet), an induced current appears. In terms of Lenz's law this pushing is the "change" that produces the induced current, and, according to this law, the induced current will oppose the "push." If we pull the magnet away from the coil, the induced current will oppose the "pull" by creating a *south* pole on the right-hand face of the loop of Fig. 35-3. To make the right-hand face a south pole, the current must be opposite to that shown in Fig. 35-3. Whether we pull or push the magnet, its motion will always be automatically opposed.

The agent that causes the magnet to move, either toward the coil or away from it, will always experience a resisting force and will thus be required to do work. From the conservation-of-energy principle this work done on the system must be exactly equal to the Joule heat produced in the coil, since these are the only two energy transfers that occur in the system. If we move the magnet more rapidly, we will have to do work at a faster rate and the rate of the Joule heating will increase correspondingly. If we cut the loop and then perform the experiment, there will be no induced current, no Joule heating, no force on the magnet, and no work required to move it. There will still be an emf in the loop, but, like a battery connected to an open circuit, it will not set up a current.

If the current in Fig. 35-3 were in the *opposite* direction to that shown, the face of the loop toward the magnet would be a south pole, which would pull the bar magnet toward the loop. We would only need to push the magnet slightly to start the process and then the action would be self-perpetuating. The magnet would accelerate toward the loop, increasing its kinetic energy all the time. At the same time Joule heat would appear in the loop at a rate that would increase with time. This would indeed be a something-for-nothing situation! Needless to say, it does not occur.

Let us apply Lenz's law to Fig. 35-3 in a different way. Figure 35-4 shows the lines of **B** for the bar magnet.* On this point of view the "change" is the increase in Φ_B through the loop caused by bringing the magnet nearer. The induced current opposes this change by setting up a field that tends to oppose the increase in flux caused by the moving magnet. Thus the field

* There are two fields of **B** in this problem—one connected with the current loop and one with the bar magnet. The student must always be certain which one is meant.

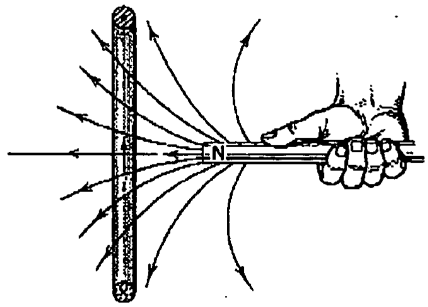

Fig. 35-4 In moving the magnet toward the loop, we increase Φ_B through the loop.

due to the induced current must point from left to right through the plane of the coil, in agreement with our earlier conclusion.

It is not significant here that the induced field opposes the magnet *field* but rather that it opposes the *change*, which in this case is the *increase* in Φ_B through the loop. If we withdraw the magnet, we reduce Φ_B through the loop. The induced field will now oppose this decrease in Φ_B (that is, the change) by *re-enforcing* the magnet field. In each case the induced field opposes the change that gives rise to it.

35-4 Induction—A Quantitative Study

The example of Fig. 35-4, although easy to understand qualitatively, does not lend itself to quantitative calculations. Consider then Fig. 35-5, which shows a rectangular loop of wire of width l, one end of which is in a uniform field $\mathbf{B}$ pointing at right angles to the plane of the loop. This field of $\mathbf{B}$ may be produced in the gap of a large electromagnet like that of Fig. 33-2. The dashed lines show the assumed limits of the magnetic field. The experiment consists in pulling the loop to the right at a constant speed v.

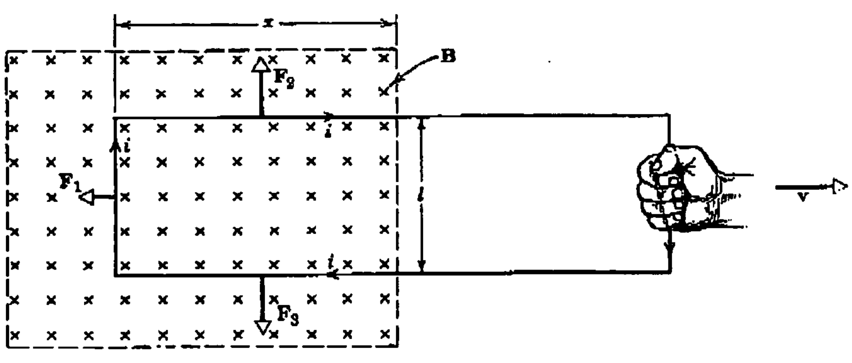

Fig. 35-5 A rectangular loop is pulled out of a magnetic field with velocity v.